# A Review of Matrix Converter and Novel Control Method of DC-AC Matrix Converter

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*Abstract*— **For the past three decades, research work in matrix converter has increased much. This paper presents a new topology of DC-AC matrix converter, starting with a brief historical review of different modulation and control strategies which was developed recently. The purpose of the Paper is to generate a multilevel output voltage equal to multilevel inverter with reduced switches. An important part of the paper is to design a dedicated DC-AC matrix converter and some new arrays of bidirectional switches in a single module are also presented. To find the performance of the module the entire module is designed with MATLAB simulation and tested with three phase induction motor.**

*Index Terms* — **AC–AC, DC-AC, Matrix Converter (MC), SVM**

## I. Introduction

Most important features for power converter circuits are adoptable for situation of change in amplitude and frequency. It should be simple and compact in size; work with UPF(Unity Power factor) for any load. The above characteristic is suitable for Matrix converter, since Matrix converter uses less switch and flexible for variable voltage and frequency. It was initially introduced as replacement for AC to AC converter, which converts input line voltage into variable voltage with unrestricted frequency without using any DC link between the converters. MC is full regenerative and sinusoidal input current with UPF, which consists of nine bidirectional switches. A small input LC filter for eliminating high frequency component connected in the input side of Matrix Converter (MC). By using suitable PWM technique all the nine switches are controlled in sequence, so as to get controlled output voltage and input current.

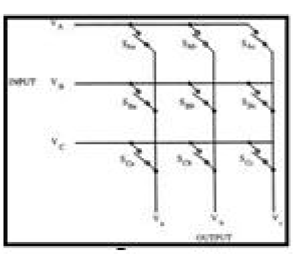

Fig. 1. Simple Matrix Converter Topology

The main drawback of the matrix converter is to commutate the bidirectional switch [1]. This paper presents some of the different modulation techniques which are used to control the switching to produce output voltage and the performance of each technique is compared and assessed. Finally a new topology is introduced to overcome the multilevel inverter, number of power semiconductor switches are needed as the level of the inverter increases. Although lower voltage rated switches can be utilized in a multilevel converter each switch requires a related gate drive circuit. This causes overall system complex.

## II. Different Modulation Techniques

There are different types of modulation techniques followed like scalar technique, Vector Control, Predictive control, Fuzzy, Neural and more techniques. The most preferred method for MC converter is Venturini Scalar technique. In 1980 Venturini and Alesina carried out the research work [2] on MC. The output voltage is obtained by the product of the input voltage and the transfer matrix. Another method in scalar technique is Roy scalar technique. In this method the instantaneous voltage ratio of specific input phases voltage to generate active and zero state. The easier method is pulse width modulation technique. In this method carrier based and SVM technique is followed to control MC. In recent period more modern techniques are introduced such as predictive control for both torque and current control of AC machine. In this paper the above techniques are compared. At the end a new topology is proposed on DC to AC Matrix Converter. The result for three phase five level matrix inverter output is assessed and discussed
with waveform.

## III. Direct Matrix Converters

In this method AC-AC converter is implemented using MC. It uses an array of m x n controlled bidirectional switches m phase input to n phase output. The ability of bidirectional switch is to block the voltage and send the current in both the direction. The output of generated variable n- phase voltage with unrestricted frequency. The advantage in AC-AC MC replaces the traditional AC-DC-AC converter. The disadvantage in AC-DC-AC is that it uses a DC link between two AC terminals. The switches in MC should be switched on in such a way that input is never short circuited and output must not be open circuit, because of the inductive nature of the load.

$$Sij(t) = \begin{cases} 1, Switch\ ON \\ 0, Switch\ OFF \end{cases} \quad (1)$$

The power filter ($R_f$, $L_f$, $C_f$) located at the input side of the converter produces almost sinusoidal source current and avoid generation of overvoltage[17]. These filter provides



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series and parallel resonance for the load circuit. The series resonance is for any harmonic coming from supply and parallel resonance for harmonics generated due to switching of converters. Due to presence of capacitor and inductive nature of load current, only one switch of each column can be closed. The mathematical module of MC is given below

$$v_o = T(S_{ij}) * v_i \tag{2}$$

$$i_i = (S_{ij})T^* i_o \tag{3}$$

Where, $v_o$, $v_i$ $i_i$ and $i_o$ are voltage and current of output and input vector respectively. $T(S_{ij})$ is the instantaneous transfer matrix of the DMC

$$T(Sij) = \begin{pmatrix} SAa & SBa & SCa \\ SAc & SBc & SCc \\ SAb & SBb & SCb \end{pmatrix} \tag{4}$$

The above equation is used to evaluate the Output voltage and Input current. For proper triggering the switches, output voltage will be obtained from matrix converter. The matrix combination switching is given in
transfer matrix.

## IV. Scalar Techniques

### *A. Venturini Method*

Venturini [2] proposed a method of generation of appropriate firing pulse to each of the nine bidirectional switch ($S_{ij}$). The main objective of Venturini modulation technique is to generate Variable amplitude ($V_{jN}$) from fixed input ($V_i$) and variable frequency from fixed frequency. $T_s$ is the total sampling interval for n number of switching closed. $T_{ij}$ is defined as the time during which switch ($S_{ij}$) is 'ON'.

$$v_{jN} = \frac{(t_{Aj}v_A + t_{Bj}v_B + t_{Cj}v_C)}{T_s} \tag{5}$$

Where $V_{jN}$ is mean value over one sampling interval of the jth output phase with j = a, b, c, and therefore, the following duty cycles can be defined:

$$mAj(t)= tAj/Ts,\ mBj(t)= tBj/Ts,\ mBj(t)= tBj/Ts \tag{6}$$

Simplifying the equation (5) and (6) the following equation obtained

$$V_o(t) = M(t)V_i(t) \tag{7}$$

where $V_o(t)$,$V_i(t)$ and M(t) is the low-frequency output, input voltage and transfer matrix respectively, and the low frequency transfer matrix of the converter is defined as

$$\begin{pmatrix} mAa(t) & mBa(t) & mCa(t) \\ mAb(t) & mBb(t) & mCb(t) \\ mAc(t) & mBc(t) & mCc(t) \end{pmatrix} \tag{8}$$

Similarly for the current $i_i(t)$

$$P_0 = \frac{3qV_i I_0 \cos\lfloor\varphi_0\rfloor}{2}$$

$$P_i = \frac{3V_i I_i \cos\lfloor\varphi_i\rfloor}{2} \tag{9}$$

Where Po and Pi are the output and input active powers respectively, $\phi$i and $\phi_0$ is the input and output displacement angle, and q is the voltage gain of the MC. With the previous definitions, the modulation problem is reduced to finding a low-frequency transfer matrix M(t) (8) is satisfied. The explicit form of the matrix M(t) can be obtained from [2] and [3], and it can be reduced to the following expression.

$$m_{ij}(t) = \frac{1}{3}\left(1 + 2v_{iN}(t)\overline{v}_{jN}/V_i^2\right) \tag{10}$$

Where, i = A, B, C and j = a, b, c. An important aspect of the solution presented is that the voltage gain of the converter cannot exceed q = 0.5 due to the working principle (mean value) and the input voltage waveforms. To increase the gain to q = $\sqrt{3}/2$ = 0.866, Venturini proposed the injection of a third harmonic, resulting in the following expression:

$$m_{ij}(t) = \frac{1}{3}(1 + \frac{2v_{iN}(t)\overline{v}_{jN}}{V_i^2} + \frac{4q}{3\sqrt{3}} \sin(\omega_i t + \beta_i)\sin(3\omega_i t)) \tag{11}$$

for i = A,B,C, j = a, b, c and βi = 0, 2π/3, 4π/3. The same gain voltage q = $\sqrt{3}/2$can be obtained by using the line-to-line voltages in the modulation.The output wave form [2] of the Venturini method shows the evident for the above discussed procedure

### *B. Roy's Method*

With the above discussed method in 1987 Roy proposed a new scalar method. It consists of using the instantaneous voltage ratio of specific input phase voltage to generate the active and zero state to the converter switch. The value of any instantaneous output phase voltage (j = a, b, c) is expressed as

$$v_{jN} = \frac{1}{T_s}\left(t_K v_K + t_L v_L + t_M v_M\right) \tag{12}$$

M has different polarity than other two inputs, L is smallest of other two inputs, k is third input. The voltage transfer ratio is limited to q ≤ 0.5. To get positive values of $t_K$, $t_L$, $t_M$ switching time of the basic scalar control laws is modified. It is possible to add the 3rd harmonic to obtain an overall voltage transfer ratio q= $\sqrt{3}/2$. Therefore modulation duty cycle of scalar method can be gives as

$$m_{ij} = \frac{1}{3}\left(1 + \frac{2v_i v_j}{V_i^2} + \frac{2}{3}\zeta\right) \tag{13}$$

For i = A,B,C, j = a, b, c, and βk = 0, 2π/3, 4π/3.Equations (13) and (10) are equal when the output voltage is maximum (q= $\sqrt{3}$ /2.). The difference between the methods is that the term q is used in the Venturini method and it is fixed at its maximum value in the Roy scalar method. The effect on the output voltage is negligible, except at low switching frequencies, where the Venturini method is superior.



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## V. PWM Methods

### A. Carrier-Based Modulation Method

The output voltage will be maintained constant with input side having UPF by controlling the PWM applied to MC has been reported in [4][5][6]. This method has very simple techniques where the sinusoidal signal is compared with standard triangular carrier wave $v_{tri}$, the switching pulse is generated by using a logical table as a function of input voltage and desired output. The different input voltages are identified by considering variable $\chi_A$, $\chi_B$, and $\chi_C$(ref table I). If the condition in the table is not satisfied then the logical variable is taken as '0'. The gate pulse pattern generated for the MC is given according to the switching state.

$$N = 16\chi_A + 8\chi_B + 4\chi_C + 2L1 + L0 \qquad (14)$$

where L0 and L1 are the output voltage levels (L0 is selected if the level of the output voltage reference is less than or equal to zero, and L1 is selected if the output voltage level is above zero).

The Unipolar SPWM method with corresponding carrier wave signal and desired output level voltage wave form is referred [6]. The Table 1 shows the different switching level.

Table I. Input Voltage States

| Condition | Value |
|---|---|
| $V_A>V_B$ | $\chi_A=1$ |
| $V_B>V_C$ | $\chi_B=1$ |
| $V_C>V_A$ | $\chi_C=1$ |

### B. SVM Method(Space Vector Modulation)

The SVM strategy was proposed [7][8]and[9] and employed to control a 3 phase-3 phase matrix converter. Although it is possible to obtain the maximum output input voltage ratio using this technique, it is not possible to control input current displacement factor. SVM treats a sinusoidal voltage as a phasor which rotates at a constant angular frequency, . This amplitude vector is represented in *d-q* plane where it denotes the real and imaginary axes. All the three modulating signals in SVM will be treated as single reference voltage, *Voref* which is related to the magnitude of output voltage of the switching topologies.

For a balanced three phase sinusoidal system the instantaneous voltages maybe expressed as

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = V_0 \begin{pmatrix} \cos \omega_0 t \\ \cos(\omega_0 t - 120) \\ \cos(\omega_0 t - 240) \end{pmatrix} \qquad (15)$$

This can be analyzed in terms of complex space vector

$$V_0 = \frac{2}{3}\left( V_a(t) + V_b(t)e^{\frac{i4\pi}{3}} + V_c(t)e^{\frac{i4\pi}{3}} \right) = V_0 e^{i\omega_0 t} \qquad (16)$$

Similarly, the space vector representation of the three phase input voltage, input current and output current is given as:

$$V_i = \frac{2}{3}\left( V_A(t) + V_B(t)e^{\frac{i4\pi}{3}} + V_C(t)e^{\frac{i4\pi}{3}} \right) = V_i e^{i\omega_i t} \qquad (17)$$

$$I_0 = \frac{2}{3}\left( V_a(t) + V_b(t)e^{\frac{i4\pi}{3}} + V_c(t)e^{\frac{i4\pi}{3}} \right) = I_0 e^{i(\omega_0 t - \phi_0)} \qquad (18)$$

$$I_i = \frac{2}{3}\left( V_A(t) + V_B(t)e^{\frac{i4\pi}{3}} + V_C(t)e^{\frac{i4\pi}{3}} \right) = V_0 e^{i(\omega_i t - \varphi_i)} \qquad (19)$$

Where, $j_i$ and $j_0$ are input and output phase angle. The parameters A, B, C and a, b, c represents the input and output voltage parameters referring figure 1.For operation of the Matrix Converter only one switch in each output phase must be conducting. This leads to 27 possible switching combinations for the Matrix Converter.The 27 possible output vectors for a three-phase matrix converter can be classified into three groups with the following characteristics.

Group I: Each output line is connected to a different input line. Output space vectors are constant in amplitude, rotating (in either direction) at the supply angular frequency.

Group II: Two output lines are connected to a common input line; the remaining output line is connected to one of the other input lines. Output space vectors have varying amplitude and fixed direction occupying one of six positions regularly spaced 60 degree apart.

Group III: All output lines are connected to a common input line. Output space vectors have zero amplitude (i.e., located at the origin)

Assuming the displacement factor of the input is zero.The maximum modulation index is given as $\sqrt{3}/2$.

## VI. Predictive Controls

### A. PCC(Predictive Current Control)

In this method the input and output current, output voltage variables are determined using state space technique. These variables are used to determine the predicted output [10].The state variable model for input and output is given as follows:

$$\frac{di_0}{dt} = \frac{1}{L_L}V_0 - \frac{R_L}{L_L}i_0 \qquad (20)$$

$$\frac{di_s}{dt} = \frac{1}{L_f}(V_s - i_i - R_f i_s) \qquad (21)$$

$$\frac{dv_i}{dt} = \frac{1}{C_f}(i_s - i_i) \qquad (22)$$


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Using the above equation predicated reactive power and load current is determined. For each sampling interval all possible switching state combination is calculated. Once the switching state is determined then corresponding weights are determined to get the predicted output, Even though this method produces predicated output the input is highly distorted so it requires very strong filter. Different techniques for MCs have been proposed under the name of PCC.

### *B. PTC (Predictive Torque Control)*

PTC is also used similar technique to produce the required output with 27 possible combinations at fixed sampling frequency. The selection is passed on quality function minimization technique, this quality function technique evaluate which switching should come for the next sampling interval.

$$V_s = R_s i_s + \frac{d\phi_s}{dt} \text{ and } V_r = R_r i_r + \frac{d\phi_r}{dt} - ip\omega\phi_r \quad (23)$$

Where, $R_s$ and $R_r$ are the stator and rotor resistances, $\phi$s and $\phi$r are the stator and rotor fluxes, $\omega$ is the mechanical rotor speed, and p is the number of pole pairs of the IM. Using the above mathematical model, the IM stator and rotor torque developed by the machine was calculated and given below

$$T_e = \frac{3}{2} p\xi(\phi_s \phi_r) \quad (24)$$

The quality function of DTC(Direct Torque Control) represents the evaluation criteria to decide which switching state is the best to apply. This leads to predict the switching state of the MC. This method also produces better result since it uses the dynamic machine model for prediction. But this produces high distortion and phase shift angel in the input current.

## VII. Review on Recent Studies About DC to AC

Most of the matrix Converter is deal with AC to AC converter for variable frequency and amplitude. SVM and Venturini methods are preferred for most of the cases to get the relevant output [1] [4]. In this paper the analysis about DC to AC matrix converter is proposed. These topologies were discussed only in few papers. The method of circuit and control techniques were discussed [11] and give the output response as square wave.

Moreover, Load used is RL load.The controlling technique was not specified much. In other paper [12] Simulation work gives idea about how to get inverted output from DC with PWM Technique. But Matrix converter techniques like SVM, Venturini is not discussed. [13] Simulation result gives how SVM can be implemented in inverter to trigger the switches in sequence to get AC output.

More Papers and articles are discussed on SVM [15] [16] method to get AC voltage. This paper gives on simulation result how Induction motor can be controlled using DC voltage under Matrix converter topology.

## VIII. DC –AC Matrix Converter

The schematic representation of simple DC to AC matrix converter is presented in Figure 2. Its input voltage is Vin and output voltage is Vo. It comprises four ideal bi-directional switches S1, S2, S3, and S4. The matrix converter will be designed and controlled in such a manner that the fundamental of the output voltage is

$$V_o(t) = V_{in}\cos(\omega_o t) \quad (25)$$

Where, Vo denotes a peak value of desired output voltage, $\omega_o$ denotes an angular frequency of output voltage. In this strategy, the sampling time Ts, will be divided into 2-time intervals t1 (Mode 1) and t2 (Mode 2) in Figure 3 b.

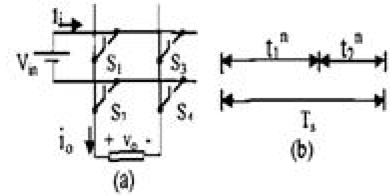


Fig. 2. (a) DC to AC matrix converter circuit configuration (b) The sampling time Ts

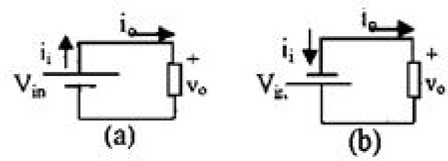


Fig. 3. (a) Equivalent circuits for DC to AC (b) Mode1 (b) Mode 2

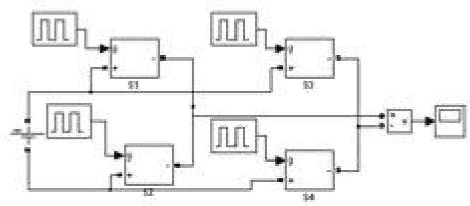

Fig. 4. Simulink model of dc-single phase matrix converter

Table II. Different Switching States

| Cases | Device ON | Conditions |
|---|---|---|
| 0 | S1, S3 Or S2, S4 | Open Circuit |
| 1 | S1, S4 | Vo |
| 2 | S2, S3 | Vo |
| 3 | S1, S2 Or S3, S4 | Short Circuit |

The Switching state of each device for single phase matrix converter is shown in Table II.According to the operation principle the DC-AC Matrix inverter circuit is simulated using Simulink shown in figure 4, the input and output voltage waveforms are determined.. The matrix converters are constituted by ideal switches. The input terminals are connected to a DC voltage source of 100V, and the output terminals are connected to the voltage measurement.

## IX. Three Phase AC Matrix Converter

The Matlab model for three phase DC to AC matrix converter is shown in Figure 5. The matrix converter will be designed and controlled in such a manner that it follows the



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fundamental output voltages equation.

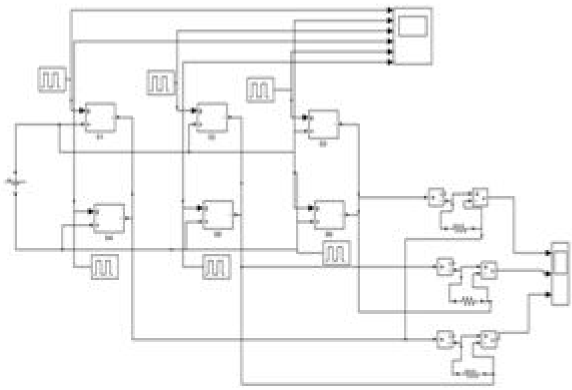

Fig. 5. DC – Three phase Matrix converter Matlab Model

The above mode is controlled using SVM technique. The simulation results are shown in Figure 6 and 7. The input terminals are connected to a DC voltage source of 100V. Simulation result of 3 level dc-three phase AC matrix converter and 5 level dc-three phase AC matrix converter are shown in Figure8. Finally, the output voltage is fed to the Induction motor and its performance curve is plotted and compared[14] is shown in figure 9.

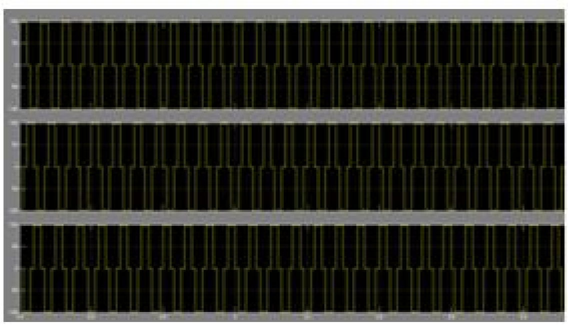

Fig. 6. DC-three level matrix converter for all three phase

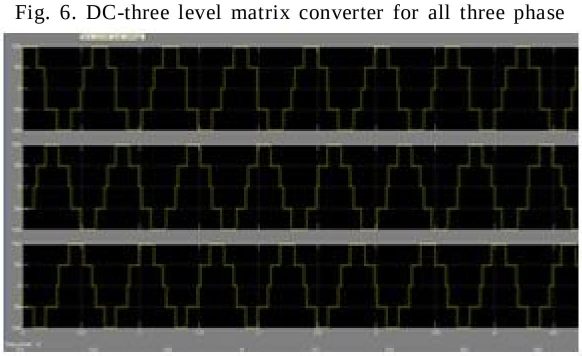

Fig. 7. DC- Five level matrix converter for all three phase

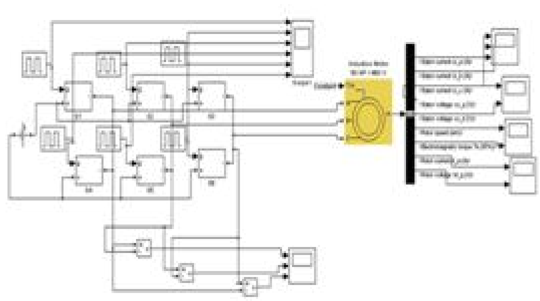

Fig. 8. DC- AC matrix converters with induction motor

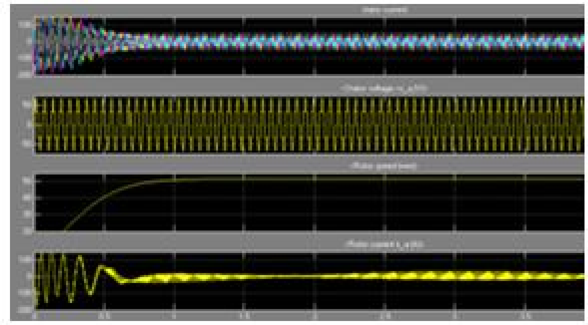

Fig. 9. Various Performance Parameter of Induction motor

## Discussion And Conclusion

In the above discussion the different techniques of MC topology are analyzed and their input, output parameters are briefly elucidated. All methods have some merits and demerits in terms of complexity, sampling frequency, switching techniques etc. But still they have good dynamic response with acceptable practical limits. In addition to this more different techniques can be applied like Fuzzy logic, neural network, Genetic algorithm etc. to have better response. At the end of the Paper a new topology of DC to AC matrix Converter is proposed. Finally, the simulations of DC to AC matrix converter are carried out using MATLAB. This paper investigates the performance of DC to AC matrix converter topologies.In particular, the study focuses on the possibility of reducing the switches for bi-directional power flow. This paper proposed the idea of getting AC voltage from DC voltage using Matrix Converter technique. The simulation results for different level were shown. To increase the level of the output more switching sequence are followed to get required output.

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